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SUBSTITUTE CONTACT MATERIAL FOR SILVER/CADMIUM OXIDE IN HOUSE WIRING SWITCHES

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ABSTRACT

To comply with upcoming legal restrictions concerning hazardous substances the contact material cadmium oxide (Ag/CdO) must be replaced in many applications. This paper deals with house-wiring switches for domestic and industrial applications. The tests were performed on commercial house-wiring switches with silver/nickel (Ag/Ni) on the fixed contact and Ag/CdO on the movable contact. A variety of silver-based contact materials such as Ag/Ni, silver/tin oxide (Ag/SnO_2) and silver/zinc oxide (Ag/ZnO) were tested in place of the Ag/CdO on the movable contact, applying lamp loads as well as capacitive loads with a rated current of 16 A at 250 V AC.
While Ag/Ni as the movable contact led to welding problems, it was found that Ag/ZnO 92/8 with silver tungstate (Ag_2WO_4) additive performed particularly well with regard to service life as well as anti-welding behavior and over temperature properties. The switching results are discussed in terms of the arc – contact material interaction and contact material micro sections after service life.

1. INTRODUCTION

The development of new installation applications in the nineteen fifties and sixties was closely linked to the development of the contact material silver/cadmium oxide (Ag/CdO) [1]. Ag/CdO is still widely used as contact material for household and installation applications.
To comply with upcoming legal restrictions in the European Union (EU) concerning hazardous substances the contact material Ag/CdO must be replaced in these applications [2]. The market therefore requires suitable contact materials.
Furthermore the electrical requirements of house-wiring switches are increasing all the time. In particular the wide spread of halogen and fluorescent lamps with higher ratings requires further modification of these house-wiring switches. Incandescent and fluorescent lamps with a high turn-on current peak (over 200 A) also make special demands on the properties of contact materials.
The minimum requirements are defined in the International Standard “IEC 60669-1” [3]. Over and above the International Standard most house-wiring switch manufacturers define their own criteria. Manufacturers test criteria usually far exceed the IEC requirements.
Received experiential knowledge of installation applications indicates that silver/zinc oxide with silver tungstate additive has a comparable switching behavior to Ag/CdO [4].
This report focuses on the switching behavior of contact materials in commercial house-wiring switches under various electrical loads, based on the International Standard “IEC 60669-1”.

2. EXPERIMENTAL

2.1 Contact Materials

The contact materials investigated in this paper are listed in table 1.
Silver/cadmium oxide (Ag/CdO) 10 is produced by an internal oxidation process (i.o.), i.e. by casting silver/cadmium alloy as a billet, extrusion and subsequent drawing or rolling, and finally an internal oxidation in an oxygen-bearing atmosphere.
All other materials are produced by powder metallurgy methods (p.m.), i.e. by blending powders, pressing a billet, extrusion and subsequent drawing or rolling. Silver/nickel (Ag/Ni) 20 and silver/zinc oxide (Ag/ZnO) 8 P have no further additives beside the respective oxide or the nickel component.
The silver/tin oxide (Ag/SnO_2) 2 PX and 8 PX materials are based on doped tin oxide powders. These additives are chemically linked on the tin oxide. Additives used with these materials are bismuth oxide and copper oxide. The doped tin oxide powders are produced by the so-called Reaction Spray Process (RSP) [5].
Ag/ZnO 6 PW25, 8 PW25 and 10 PW25 materials have a silver tungstate additive. In the first step the ZnO powder is blended with the silver tungstate, followed by an annealing process at a temperature above the melting point of the silver tungstate. This coated ZnO powder is mixed with silver before proceeding with the steps described above [6].
All materials were joined to the rocking contact carrier by direct wire riveting, resulting in rivet head size of 2.5 mm diameter and 0.7 mm height.

2.2 Set-up of Test Actuator Device

For the electrical tests a special actuator device was constructed to actuate the house-wiring switches and to identify sticking and welding of the contacts during the tests.
The detailed actuator device is shown in figure 1.
The movable arbor is driven by an air actuator. On the

No.	Material	Silver content / wt.-%	Additives	Electrical conductivity / $m/\Omega mm^2$	Remarks
1	Ag/Ni 20	80	-	48 – 51	p.m.
2	Ag/CdO 10	90	-	48 – 49	i.o.
3	Ag/SnO_2 2PX	98	Bi_2O_3, CuO	58 – 59	p.m. based on RSP
4	Ag/SnO_2 8PX	92	Bi_2O_3, CuO	51 – 52	p.m. based on RSP
5	Ag/ZnO 8P	92	-	48 – 49	p.m.
6	Ag/ZnO 6PW25	94	Ag_2WO_4	51 - 52	p.m., coated oxide
7	Ag/ZnO 8PW25	92	Ag_2WO_4	49 - 50	p.m., coated oxide
8	Ag/ZnO 10PW25	90	Ag_2WO_4	46 - 47	p.m., coated oxide

Table 1: *Contact materials*

arbor two springs are fixed. Between these two springs the arbor is connected mechanically to the main actuator. The main actuator and two modified ball-bearings switch the house-wiring switch. Depending on the force required to turn on or turn off the house-wiring switch the system can detect nearly every sticking and, of course, welding of the contacts.

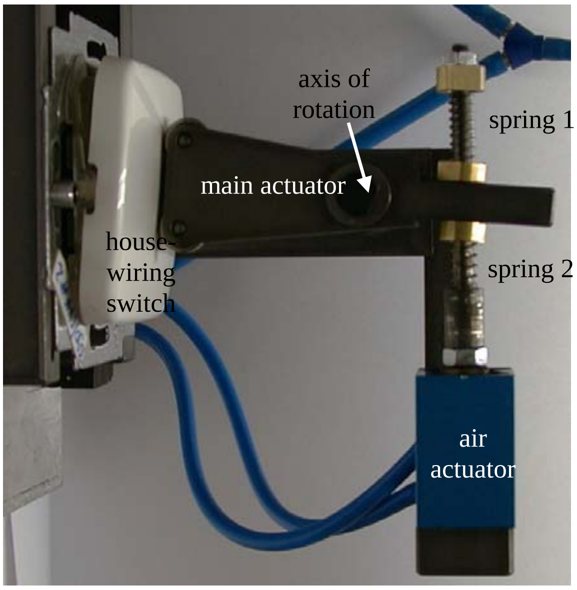

Figure 1: Set-up of actuator device

The two poles are switched simultaneously using a single switch handle. As contact materials in all switches Ag/Ni 20 was used on the fixed contact and usually Ag/CdO 10 i.o. on the movable contact. A variety of silver-based contact materials such as Ag/Ni, Ag/SnO_2 and Ag/ZnO were tested in place of Ag/CdO on the movable contact. These contact materials are shown in table 1.

The joining of the contact materials as well as the assembly of the switches was carried out under normal factory mass-production conditions.

2.3 Test Samples

The tests were performed on one commercial two-pole house-wiring switch with a rated current of 16 Amperes (A) alternating current (AC) at a rated voltage of 250 Volts (V). The wiring diagram is shown in figure 2.

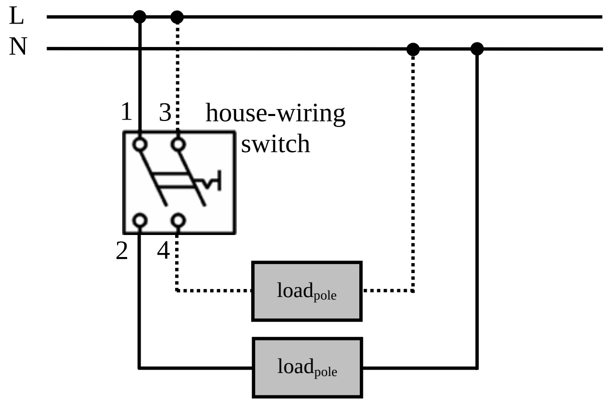

Figure 2: Wiring diagram for electrical service life test with terminal numbers

3. ELECTRICAL TESTS

All electrical tests were based on the International Standard “IEC 60669-1” [3]. In order to characterize the different contact materials clearly, additional tests were performed. Typically electrical service life tests for house-wiring switches were performed to prepare the switches for the following tests such as high-voltage, temperature rise, insulation resistance and electric strength.

Two different electrical test sequences were performed, based on the above mentioned standard:

I. Making and breaking capacity:

a) Inductive load:
- 1.1 times rated voltage (275 V);
- 1.25 times rated current (20 A, AC);
- 200 operations (at a uniform rate);
- Cos φ = 0.3.

b) Incandescent lamp load:
   - Rated voltage of lamps (240 V);
   - 200 operations (at a uniform rate);
   - 4600 W (23 x 200 watt tungsten filament lamps in parallel);
   - Quantity of sticking was counted (if a sticking occurred, the switch was opened manually and the test continued).

c) Normal operation:
   - Rated voltage (250 V);
   - Rated current (16 A, AC);
   - 40,000 operations (at a uniform rate);
   - Cos φ = 0.6.

II. Fluorescent lamp loads:

a) Load A:
   - Rated voltage (250 V);
   - Rated current (16 A, AC);
   - 5,000 operations (at a uniform rate);
   - cos φ = 0.9 (with R, C & L)
   - Wiring diagram is shown in figure 3.1;
   - Quantity of sticking was counted (if a sticking occurred, the switch was opened manually and the test continued).

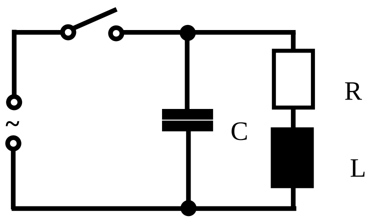

Figure 3.1: Wiring diagram of load A

b) Load B:
   - Rated voltage (250 V);
   - Rated current (16 A, AC);
   - 100 operations (at a uniform rate);
   - C = 7.3 μF, L = 0.5 H, R = 1.3 Ω;
   - Wiring diagram is shown in figure 3.2.

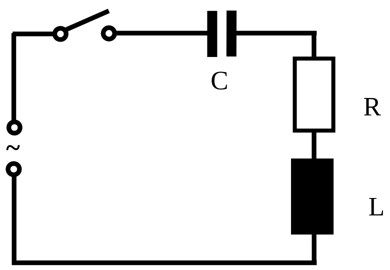

Figure 3.2: Wiring diagram of load B

For both electrical tests “making and breaking capacity” and “fluorescent lamp loads” new samples were used. At least three samples for every test sequence were tested. All service life tests were performed with a switching frequency (at a uniform rate) of 15 operations per minute.

Please note: The understanding of the term ‘operation’ in IEC 60669-1 for electrical service life of house-wiring switches differs from the common understanding as, for example, for contactors: for contactors one service life operation consists of a make with a subsequent break operation. With wiring switches any pushing of the switch means one operation. Thus a make with a subsequent break is seen as two operations.

After these service life tests further testing was performed in order to characterize the contact material:

a) Electric strength test (accord. to IEC 60669-1):
   - Voltage of substantially sine wave form, having a frequency of 50 Hz;
   - Switch set in the “off” position;
   - Sequence I: between term. 1+2 and 3+4;
   - Sequence II: between term. 1+4 and 3+2; (for terminal numbers see figure 2)
   - Voltage applied: 1500 V for 1 minute;
   - Requirement: no flashover or break-down.

b) Electric strength test (additional):
   - Switch set in the “off” position;
   - Sequence I: between term. 1+2 and 3+4;
   - Sequence II: between term. 1+4 and 3+2; (for terminal numbers see figure 2)
   - Ramp step: 50 V / sec;
   - Ramp up voltage from 0 to 5,000 V until a flashover or breakdown occurred.

c) Temperature rise:
   - Switches mounted vertically;
   - Switch mounted in a wooden block;
   - Connected conductors with a length of at least 1 m;
   - Switch set in the “on” position
   - Loaded for 1 h with rated current (16 A);
   - Over temperature was measured at the terminals by means of thermocouples;
   - Temperature rise shall not exceed 45 Kelvin.

4. TEST RESULTS

The test results obtained under various test sequences with the tests described in section 3 are summarized in figures 4.1.1, 4.1.2, 4.1.3, 4.2.1, 4.2.2 and 4.2.3.
The maximum, average and minimum voltages during the electric strength test are shown in figure 4.1.1 for the test sequence “making and breaking capacity” and in figure 4.2.1 for the test sequence “fluorescent lamp load”.

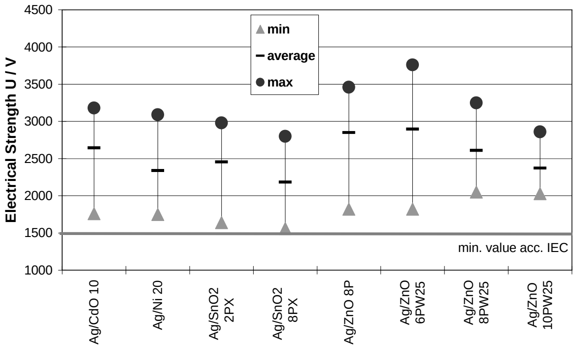

Figure 4.1.1: Electric strength test after "making and breaking capacity" test

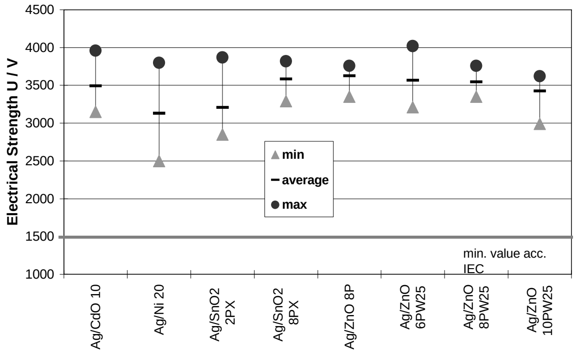

Figure 4.2.1: Electric strength test after test "fluorescent lamp loads"

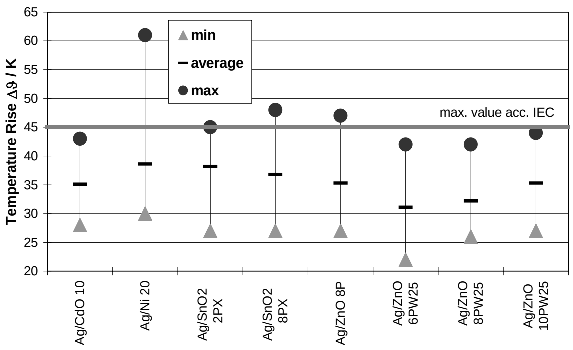

Figure 4.1.2: Temperature rise test after "making and breaking capacity" test

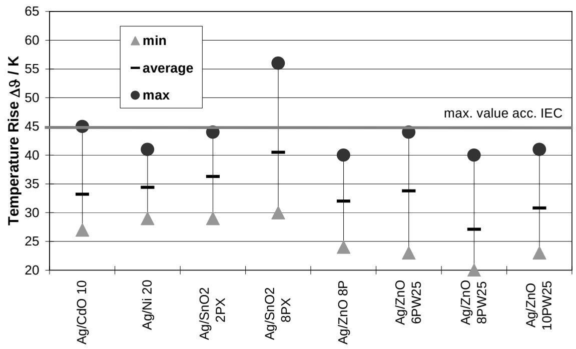

Figure 4.2.2: Temperature rise test after "fluorescent lamp loads" test

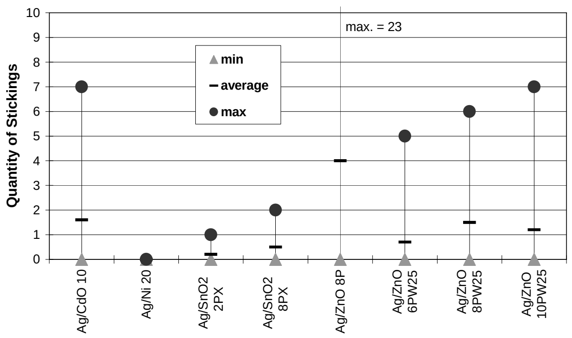

Figure 4.1.3: Anti welding property: quantity of sticking during "incandescent lamp load" test

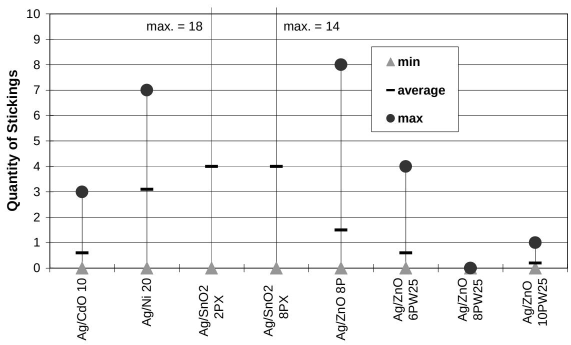

Figure 4.2.3: Anti welding property: quantity of sticking during "fluorescent lamp load A" test

Temperature rise results, minimum, average and maximum values are shown in figure 4.1.2 for the test sequence "making and breaking capacity" and in figure 4.2.2 for the test sequence "fluorescent lamp load".

The anti welding property of the tested contact materials are shown in figure 4.1.3 during the test sequence "incandescent lamp load" and in figure 4.2.3 during the test sequence "fluorescent lamp load A".

5. DISCUSSION

5.1 Electric Strength Test

During the electric strength test there were no apparent significant differences between the contact materials tested. All materials passed the minimum requirement: "no flashover or breakdown shall occur during the test at a voltage of 1500 V" [3]. The situation changed when the applied voltage was increased from 1500 V to 2000 V: only two contact materials, Ag/ZnO 8PW25 and 10PW25, fulfilled the condition after the making and breaking capacity test. The situation after the fluorescent lamp load test was uncritical.

5.2 Temperature Rise

The temperature rise at the terminals, according to the standard, shall not exceed 45° Kelvin. After the test sequence “making and breaking capacity” Ag/Ni 20, Ag/SnO_2 8PX and Ag/ZnO 8P, and after the test sequence “fluorescent lamp load” Ag/SnO_2 8PX did not meet this required standard (see figures 4.1.2 and 4.2.2). Arc loading (turn-on current peaks: > 200 A) caused different effects on the material structure of the tested contact materials. It led to a strong thermal load at the contact surface resulting in large molten contact areas.

Ag/CdO 10 i.o. shows the formation of silver-rich layers in the contact material on its surface, see figure 5.1. Ag/Ni 20 shows clearly distinct areas (see fig. 5.2): while area ❶ shows the original Ag/Ni 20 microstructure obtained by extrusion, areas ❷ to ❺ have been affected by the action of the arc. Area ❷ shows fine Ni precipitations dispersed in Ag which are generated by a certain quantity of liquid Ni dissolving in the liquid Ag at high temperatures and subsequently precipitating out after extinction of the arc. Area ❸ is in principle the same as area ❷, but due to the presence of oxygen the Ni particles have oxidized and formed black NiO particles. Area ❹ consists of pure nickel, which represents the excess nickel not dissolved in liquid Ag due to limited solubility even at temperatures as high as the boiling point of Ag. When these large areas of pure Ni touch the surface, thick layers of NiO are formed as can be seen in area ❺. Such layers cause high contact resistance, especially when they occur on both fixed and movable contacts [7, 8].

The situation with Ag/SnO_2 8PX on the movable contact was similar because there was a significant transfer of Ag/Ni 20 from the fixed contact to the movable contact (figure 5.3). The reason for this material transfer is unclear. The Ag/Ni 20 on the Ag/SnO_2 8PX contacts led to a strong thermal load at the contact surface resulting in larger molten contact areas.

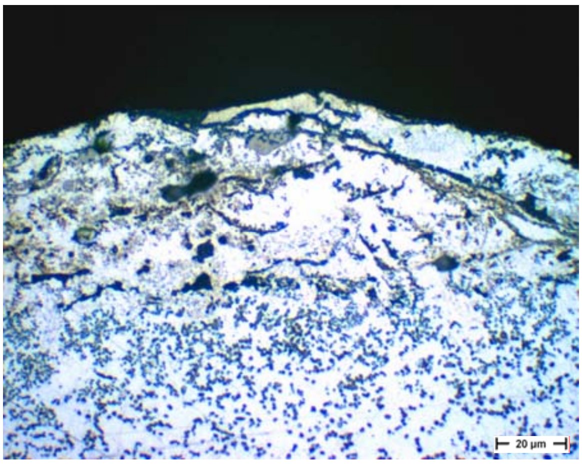

Figure 5.1: Microsection of Ag/CdO 10 i.o. (movable contact) after “fluorescent lamp load” test

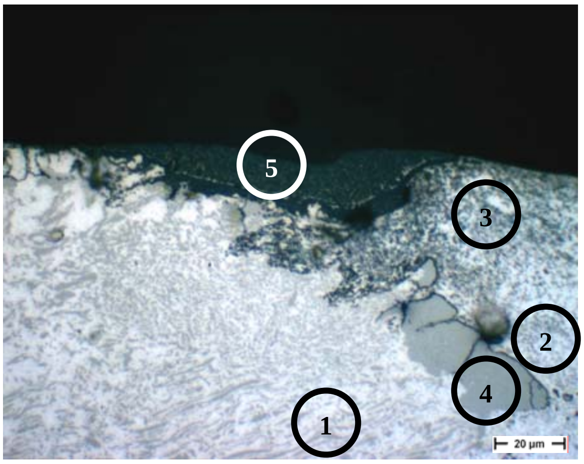

Figure 5.2: Microsection of Ag/Ni 20 (movable contact) after “fluorescent lamp load” test

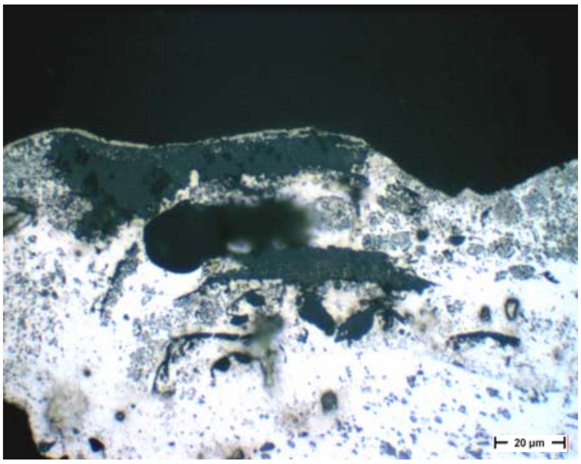

Figure 5.3: Microsection of Ag/SnO_2 8 PX (movable contact) after “fluorescent lamp load” test

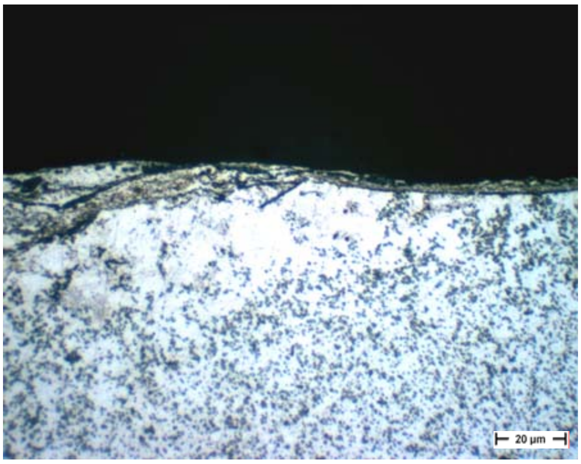

Figure 5.4: Microsection of Ag/ZnO 8 P (movable contact) after “fluorescent lamp load” test

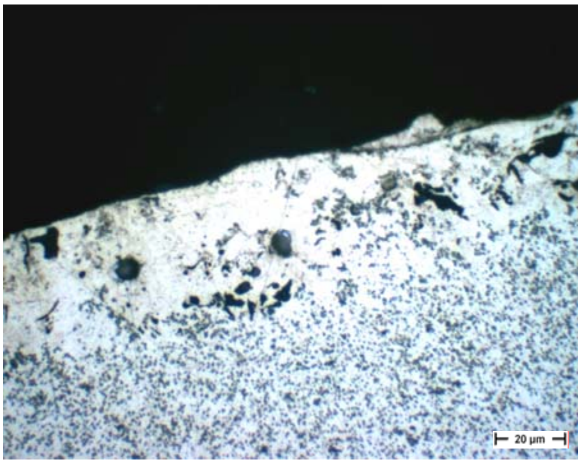

Figure 5.5: Microsection of Ag/ZnO 8 PW25 (movable contact) after "fluorescent lamp load" test

A different situation is expected if Ag/SnO_2 8 PX is used on both the fixed and the movable contact.
Ag/ZnO 8P without any further additives showed a modest temperature rise behavior, due to the formation of layers on the surface as shown in figure 5.4.
The arc treated surface of the Ag/ZnO 8 PW25 contact material with a silver tungstate additive did not exhibit the formation of ZnO layers. The deposited material shows a fine and uniform structure in the microsection and little formation of layers on the surface of the material (figure 5.5).

5.3 Anti-welding Properties

Besides the finding that none of the stickings observed was a real welding that could not be broken by manual actuation, the anti-welding properties of the contacts differ between the contact materials tested.
With the test sequence "making and breaking capacity" Ag/ZnO 8P and with the test sequence "fluorescent lamp load" Ag/ZnO 8P, Ag/SnO_2 2PX and Ag/SnO_2 8PX showed a high quantity of stickings (see figures 4.1.3 and 4.2.3).
The situation with Ag/SnO_2 8PX is similar to the situation mentioned in section 5.2 (Temperature Rise): a significant material transfer of Ag/Ni 20 from the fixed contact to the movable contact (Ag/SnO_2) took place, which is shown in figure 5.3. Ag/Ni 20 was probably responsible for the high quantity of stickings.
Using Ag/SnO_2 8PX on both contacts gave quite different results. These applications have already shown promising results.
Ag/ZnO 8P without any further additives showed a high quantity of stickings after both test sequences, which was due to the tendency toward separation of silver and zinc oxide forming zinc oxide layers as shown in figure 5.4.
Ag/ZnO 8 PW25 contact material with a silver tungstate additive did not show a great tendency toward separation of silver and zinc oxide or to the formation of zinc oxide layers (see figure 5.5). All three Ag/ZnO materials with a silver tungstate additive that were tested showed good anti-welding behavior.

6. SUMMARY

The results are summarized in table 2.
According to this table, in the applications tested the contact material combination with Ag/Ni20 as the fixed contact and Ag/CdO 10 as the movable contact showed the good switching behavior expected.
Ag/Ni 20 on both contacts did not meet the standards because of excessively high over temperatures in the temperature rise test and is thus not suitable for 16 A house-wiring switches.
Ag/SnO_2 2PX and 8 PX, containing doped SnO_2 with Bi_2O_3 and CuO additives behaved well in the electric strength test. Disadvantages of these two materials were the quantity of sticking during the tests as well as inadequate over temperature behavior arising from material transfer.
Ag/ZnO 8P without further additives had a pronounced tendency to sticking and welding.
Ag/ZnO 6PW25, 8PW25 and 10PW25, containing ZnO coated with a small amount of silver tungstate, showed good results in the electric strength and temperature rise tests. The anti-welding properties were also good. The overall best material of these three was Ag/ZnO 8PW25 which even outperformed Ag/CdO.
Bearing in mind the workability of these three materials (Ag/ZnO 6PW25 has excellent, Ag/ZnO 8PW25 good and Ag/ZnO 10PW25 fair properties), it can be claimed that a suitable alternative for Ag/CdO should be available for any future wiring switch application.

Contact material* (movable contact)	**Electric strength test**		**Temperature rise**		**Anti-welding properties**	
Load I / II:	**I**	**II**	**I**	**II**	**I**	**II**
Ag/CdO 10	0	+	+	0	+	+
Ag/Ni 20	0	+	-	+	+	0
Ag/SnO_2 2PX	0	+	0	+	+	-
Ag/SnO_2 8PX	0	+	-	-	+	-
Ag/ZnO 8P	0	+	-	+	-	-
Ag/ZnO 6PW25	0	+	+	+	+	+
Ag/ZnO 8PW25	+	+	+	+	+	+
Ag/ZnO 10PW25	+	+	+	+	+	+

Table 2: Summary:
Fixed contact always Ag/Ni 20
Load I: Making and breaking capacity
Load II: Fluorescent lamp loads
+ = good; O = average; - = poor

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